DOE Kickoff Meeting: The TERESA Study

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Overview of Presentation

- TERESA Overview
- Background and Motivation
- Study Design
- Study Basics
- Study Funding Timeline and Framework
- Study Objectives
- Study Methods
- Laboratory results: Reaction Chamber Performance
- Project Scope of Work
- Project Administration: Team, Schedule, Deliverables

TERESA: Toxicological Evaluation of Realistic Emissions of Source Aerosols

- Primary Objective: Determine the toxicity of *realistic* coal combustion emissions.
- Approach:
  - Evaluate toxicity of *secondary* coal combustion emissions at multiple power plants in the U.S. by exposing laboratory rats to a variety of simulated atmospheric scenarios.
  - Determine relative toxicity of coal combustion and mobile source emissions, as well as ambient $PM_{2.5}$ (concentrated ambient particles; CAPs).

Background and Motivation

- **Key issue**: increase our understanding of the *sources* and *components* of air pollution responsible for health effects.
- Two sources of information exist on the health effects of coal-fired power plant PM:
  - Studies examining the health effects of <u>components</u> of coal combustion emissions (e.g., sulfate, sulfuric acid). Epidemiology, toxicology, controlled human exposure studies.
  - Studies examining the health effects of <u>coal fly ash</u>. Toxicology studies only (instillation and inhalation).

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Limitations of Coal Fly Ash Studies

- Studies using primary CFA collected from ESPs:
  - Low quantities of primary CFA are emitted from U.S. power plants
  - Possible differences between collected particles and those that penetrate the ESPs into the ambient environment.
  - Populations are exposed to *secondary* PM.
  - Instillation and *in vitro* studies tend to involve very high doses.
  - Possible changes in PM characteristics during storage.
- Inhalation exposure studies:
  - Secondary PM issue (as above).
  - All studies have used pilot combustors: emissions from pilot combustors may differ from full-scale plants due to differences in surface area/volume ratios and therefore time-temperature histories.

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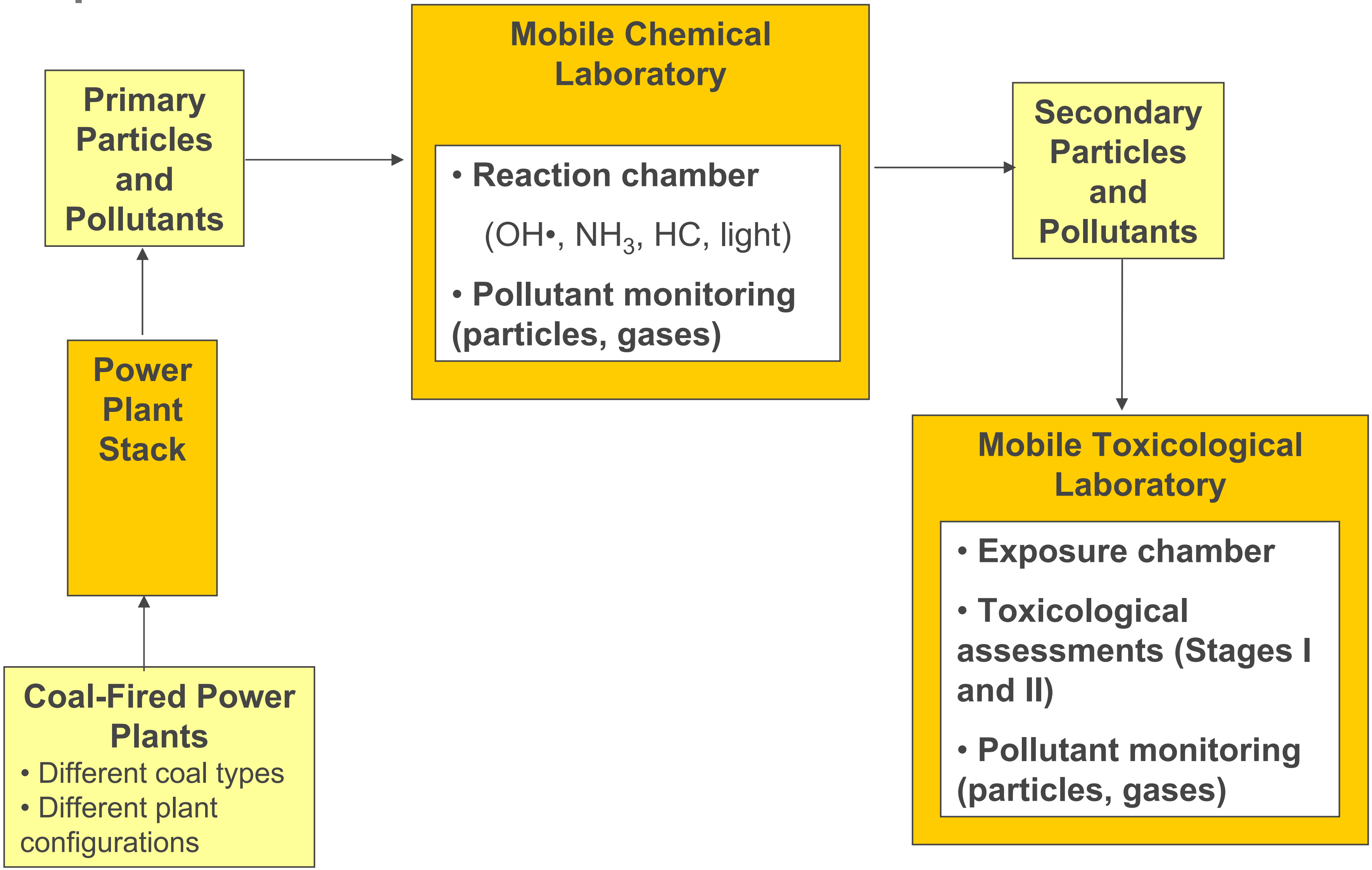
Knowledge Gaps

- No information on the toxicity of secondary particles formed through SO_2 conversion in the atmosphere.
- No assessment of the toxicity of actual plant emissions.

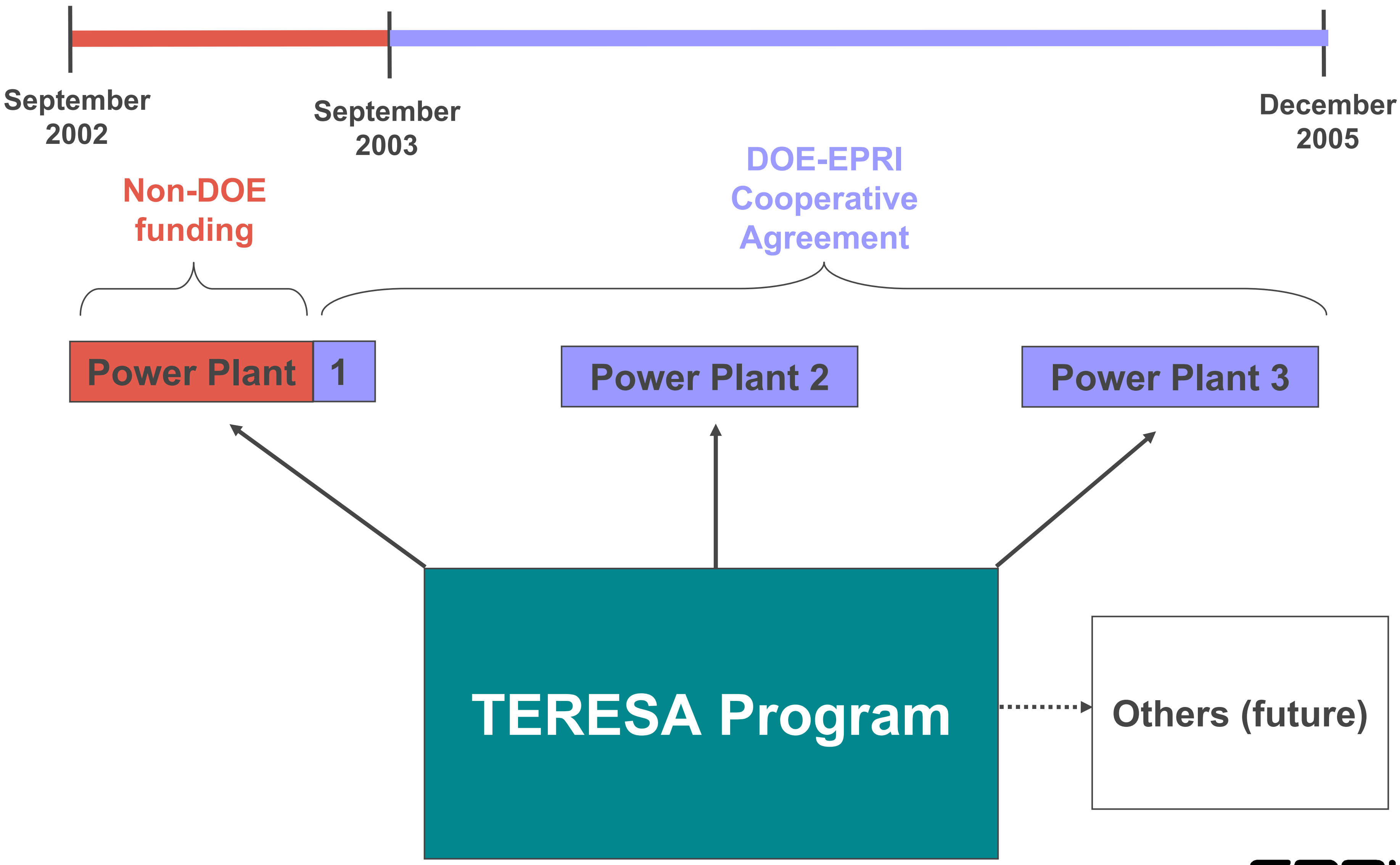
Study Design



Study Basics

- EPRI Project Manager: Dr. Annette Rohr
- DOE Project Manager: Bill Aljoe
- Key Subcontractor: Harvard University School of Public Health (Drs. Petros Koutrakis and John Godleski)
- Contract Period: September 1, 2003 to December 31, 2005

Funding Timeline and Framework



Objectives

Primary Goal:

- Investigate and clarify the impact of the sources and components of $PM_{2.5}$ on human health via a set of realistic animal exposure experiments.

Specific Objectives:

- Investigate the relative toxicity of coal combustion emissions and mobile source emissions, their secondary products, and ambient particles.
- Assess the effect of atmospheric conditions on the formation/toxicity of secondary particles from coal combustion and mobile source emissions.
- Evaluate the impact of coal type and pollution control technologies on emissions toxicity.
- Increase understanding of toxicological mechanisms of PM-induced effects.

Methods

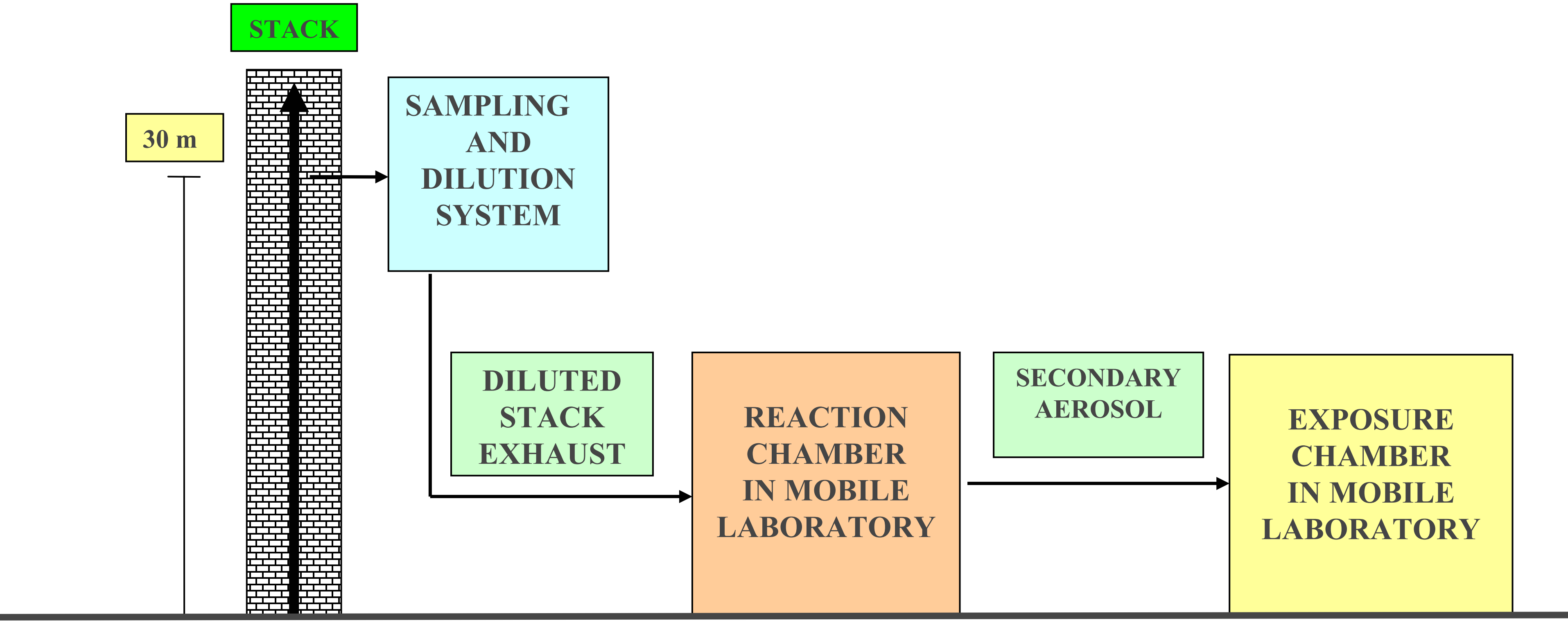
- Plant selection
- Stack sampling/dilution system
- Atmospheric reaction simulation system
- Exposure scenarios/characterization
- Animal exposure and toxicological assessment
- Mobile source and CAPs assessment

Plant Selection

Program currently includes 3 coal-fired plants (with additional plants planned):

1. Upper Midwest: PRB coal (low sulfur, low ash).
2. Southeast: low sulfur (<1%) eastern bituminous coal, no scrubber for post-combustion SO_2 removal, with or without selective catalytic reduction (SCR) for NOx removal.
3. East: medium-to-high sulfur (>2-3%) eastern bituminous coal, scrubbed unit, with or without SCR.

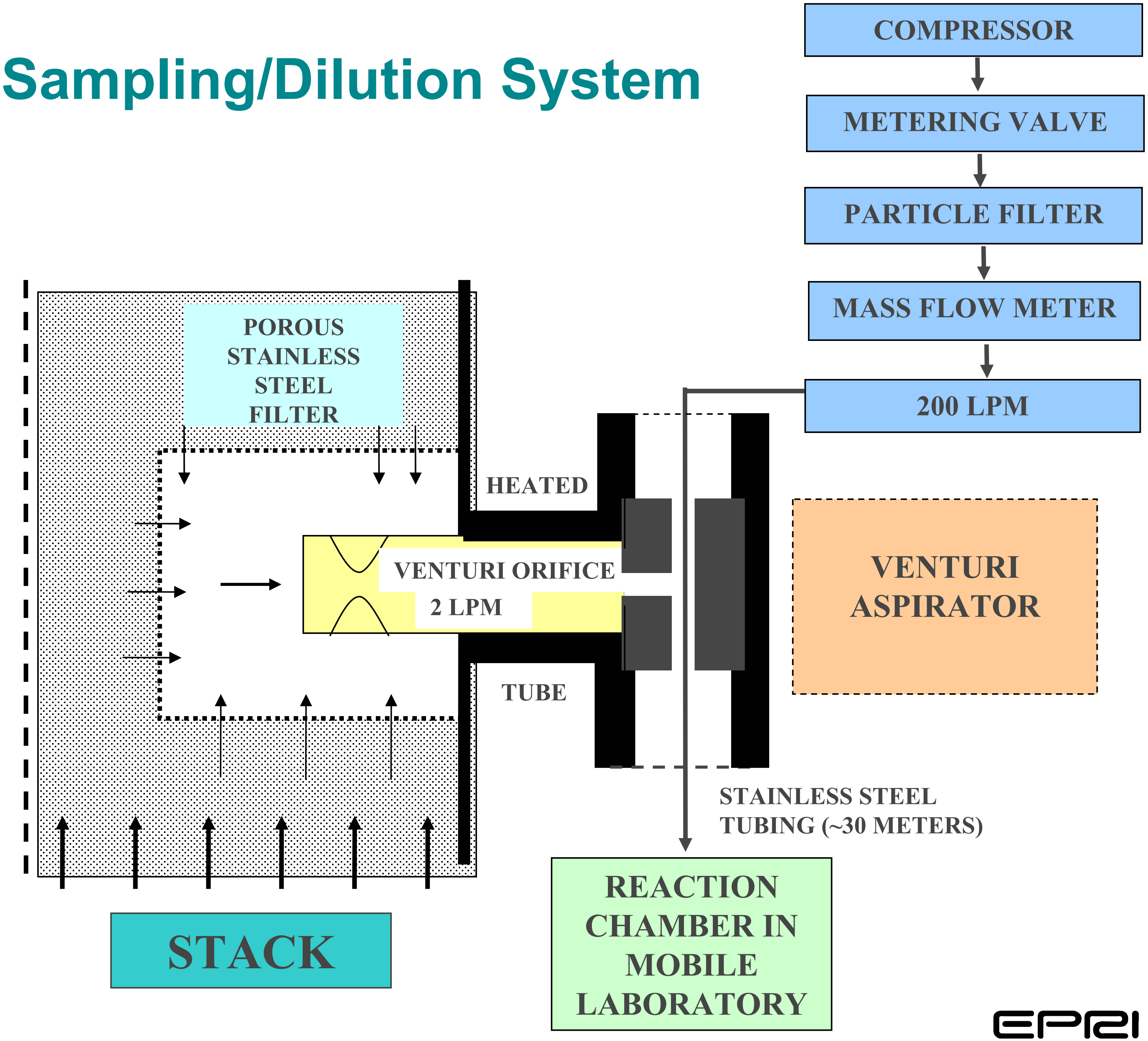
Field Layout



Stack Sampling/Dilution System

- Sample from duct leading to stack, post-ESP.
- Stainless steel fine mesh screen to remove particles > 10μm.
- Novel design: Venturi critical orifice and Venturi aspirator to control flow of dilution air.
- Diluted stack gas transported to reaction chamber through a 30-meter long stainless steel tube.

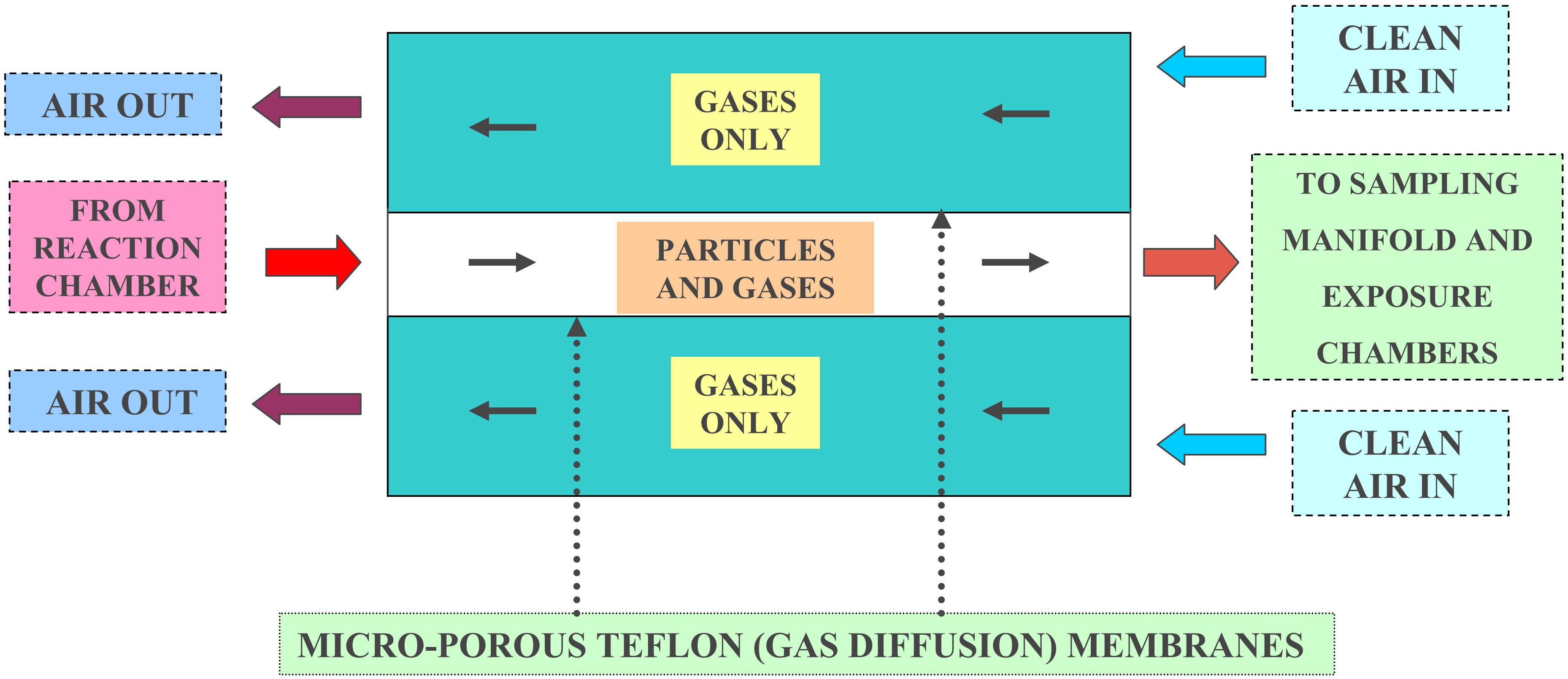
Stack Sampling/Dilution System



Atmospheric Reaction Simulation System

- **Critical component of TERESA study design**.
- Add atmospheric oxidants (OH radicals) to convert SO_2 and NOx in stack gas to sulfuric acid and nitric acid.
- Chamber designed to oxidize ~30% of SO_2 to sulfuric acid in about 60 minutes.
- Other atmospheric components introduced to chamber:
  - $NH_{3(gas)}$ to partially neutralize acidic sulfate particle strong acidity.
  - VOCs (terpenes) to simulate the formation of secondary organic aerosol from the plume mixing with biogenic emissions.
- Novel "gas-cleaning system" has been designed and evaluated. System uses a gas-permeable membrane to removal excess SO_2, NOx, ozone, and other pollutant gases while maintaining the secondary particles.

Diffusion Denuder/Gas Cleaner



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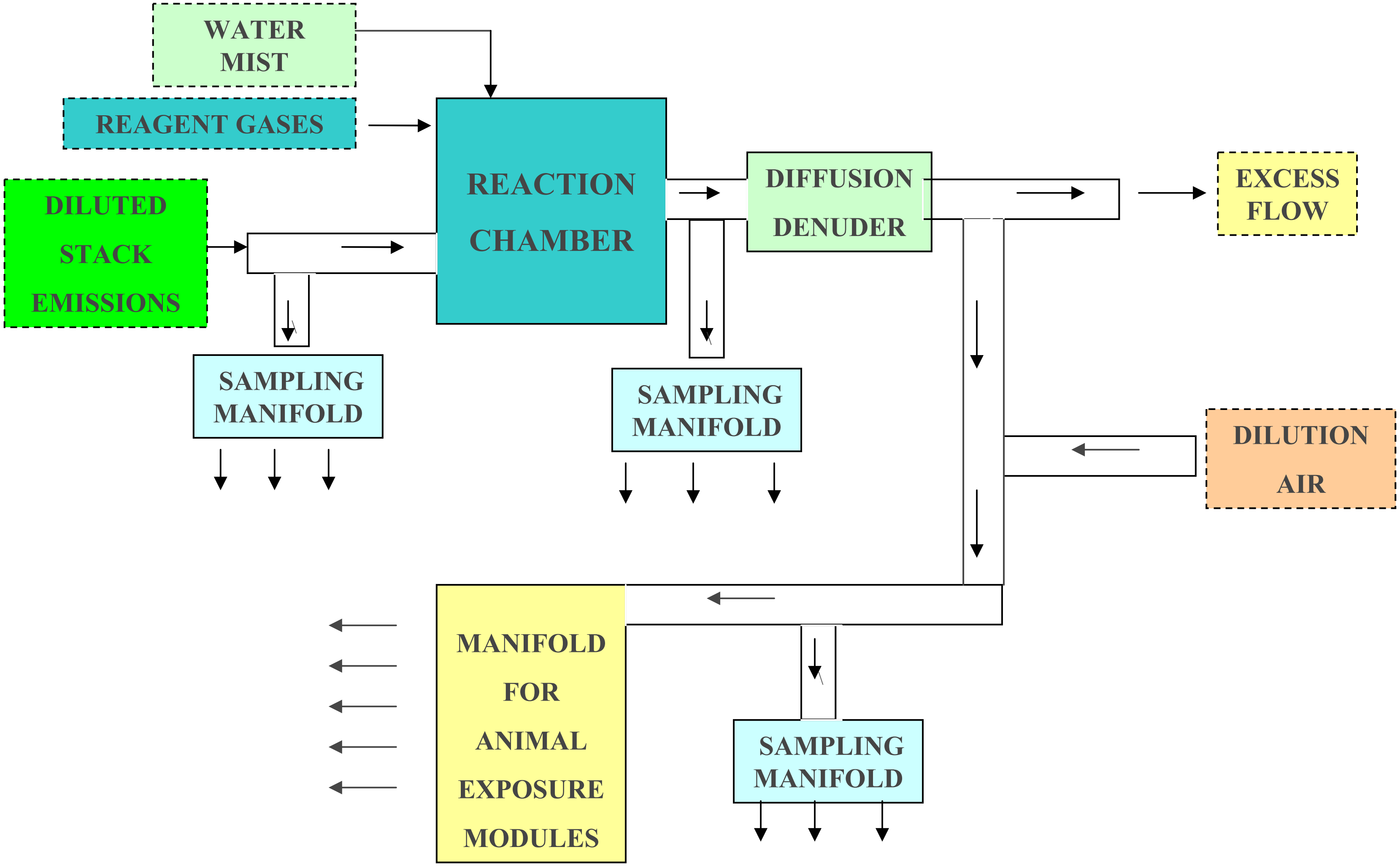
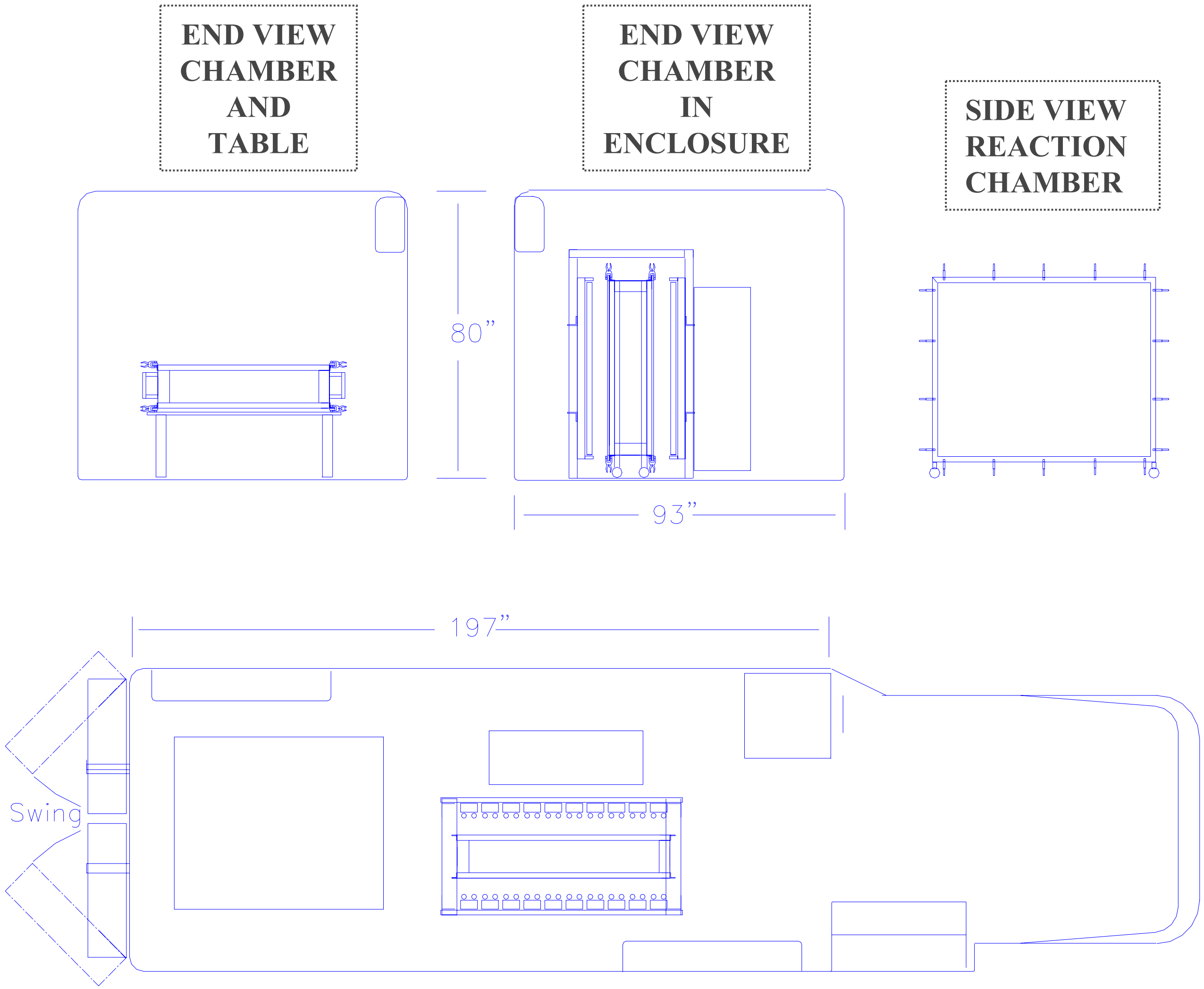
Reactor Flow and Sampling Systems

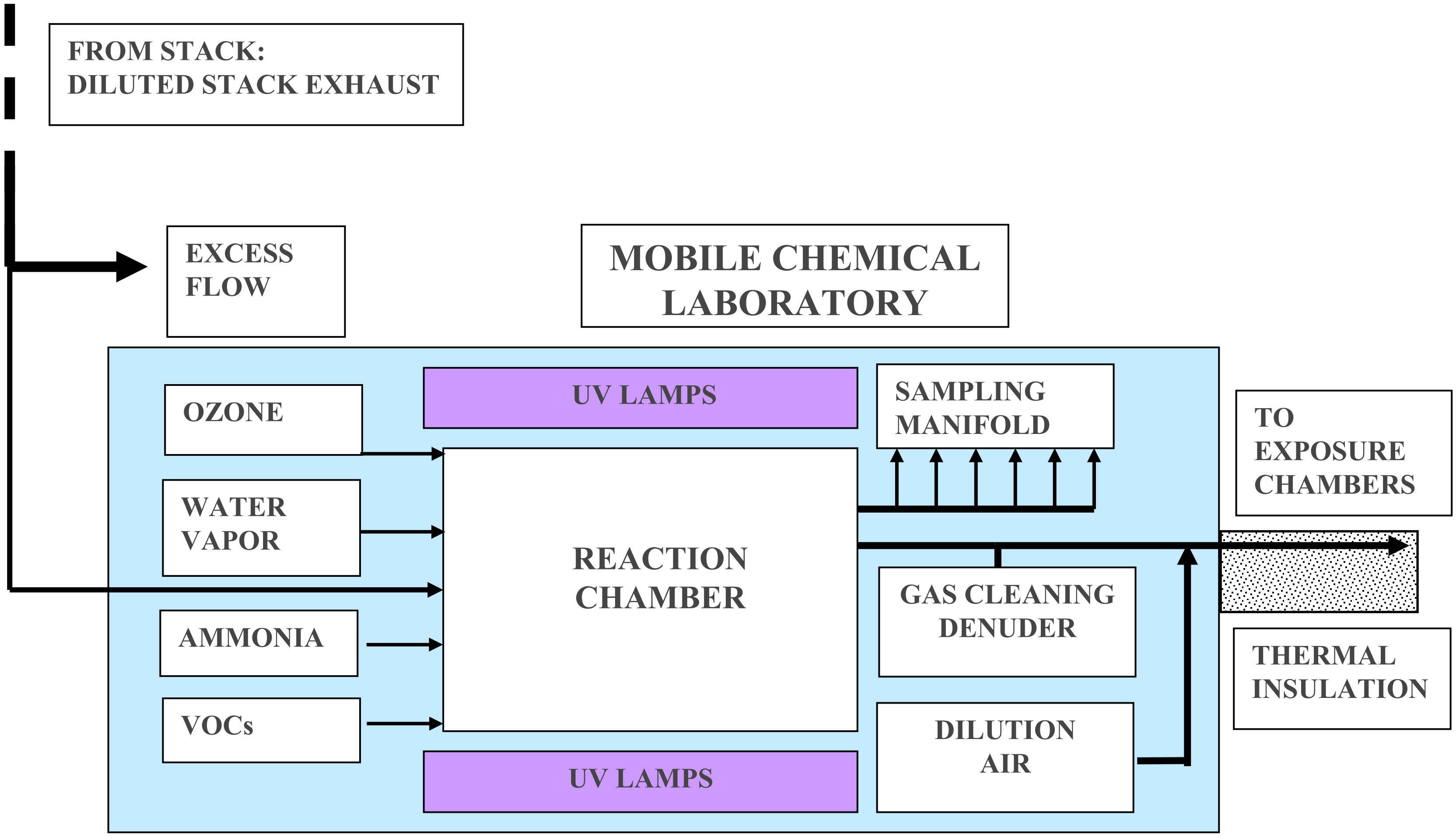


Mobile Chemical Laboratory

Mobile Chemical Laboratory Layout



Reaction Chamber



Reaction Chamber

Dimensions: 120 x 80 x 35 cm

Nominal volume: 340 L

Experimental volume: 364 L

Lights: 30 x 4’ lamps

Flow: 5 LPM

Average residence time: 72 min

Photolyis of NO_2 with BL =0.007 s^{-1}

Shielding box

Ventilation 300 cfm

Max 31º C

RH with lights on ~50%

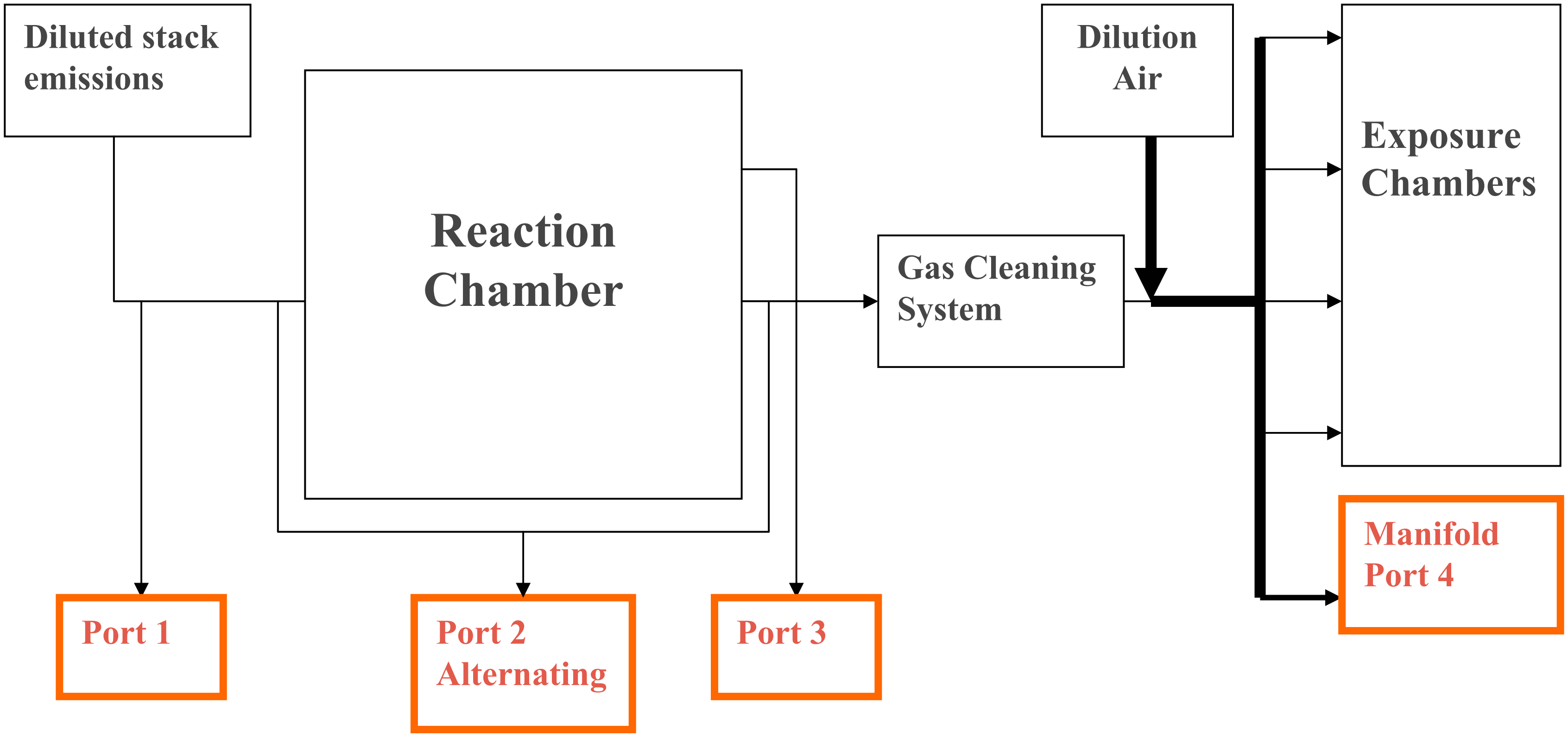
Exposure Scenarios

Scenario	Composition	Simulated Atmospheric Condition
1	Gas- and particle-free air	Sham exposure
2	Primary (un-aged) emissions diluted to ~ 50 $\mu g/m^3$ SO_2 using clean air (same dilution as for 3, 4, and 5 below)	Primary stack emissions
3	Primary emissions + hydroxyl radicals (aim is 30% conversion of SO_2 to H_2SO_4)	Aged plume, oxidized stack emissions, sulfate aerosol formation
4	Primary emissions + hydroxyl radicals + ammonia (aim is 85-90% neutralization)	Aged plume, SO_4 aerosol partially neutralized by NH_3
5	Primary emissions + hydroxyl radicals + ammonia + VOCs (aim is 30% secondary organic aerosol)	Aged plume, mixture of neutralized SO_4 and SOA from biogenic emissions
6	Atmospheric components only (of the scenario inducing the largest effect in 3, 4, and 5 above.	Emissions control exposure

Exposure Characterization

- PM mass, number, size distribution (including ultrafines)
- PM components:
  - Sulfate, nitrate
  - EC/OC
  - Ammonium
  - Metals
  - Particle strong acidity
  - Selected organics (eg. PAHs)
- Gaseous pollutants:
  - CO
  - NO_2
  - SO_2
  - Ozone
  - NH_3
  - Selected carbonyls (e.g., formaldehyde, acetone, acetaldehyde)

Location of Sampling Ports



Summary of Sampling Locations and Analytical Methods

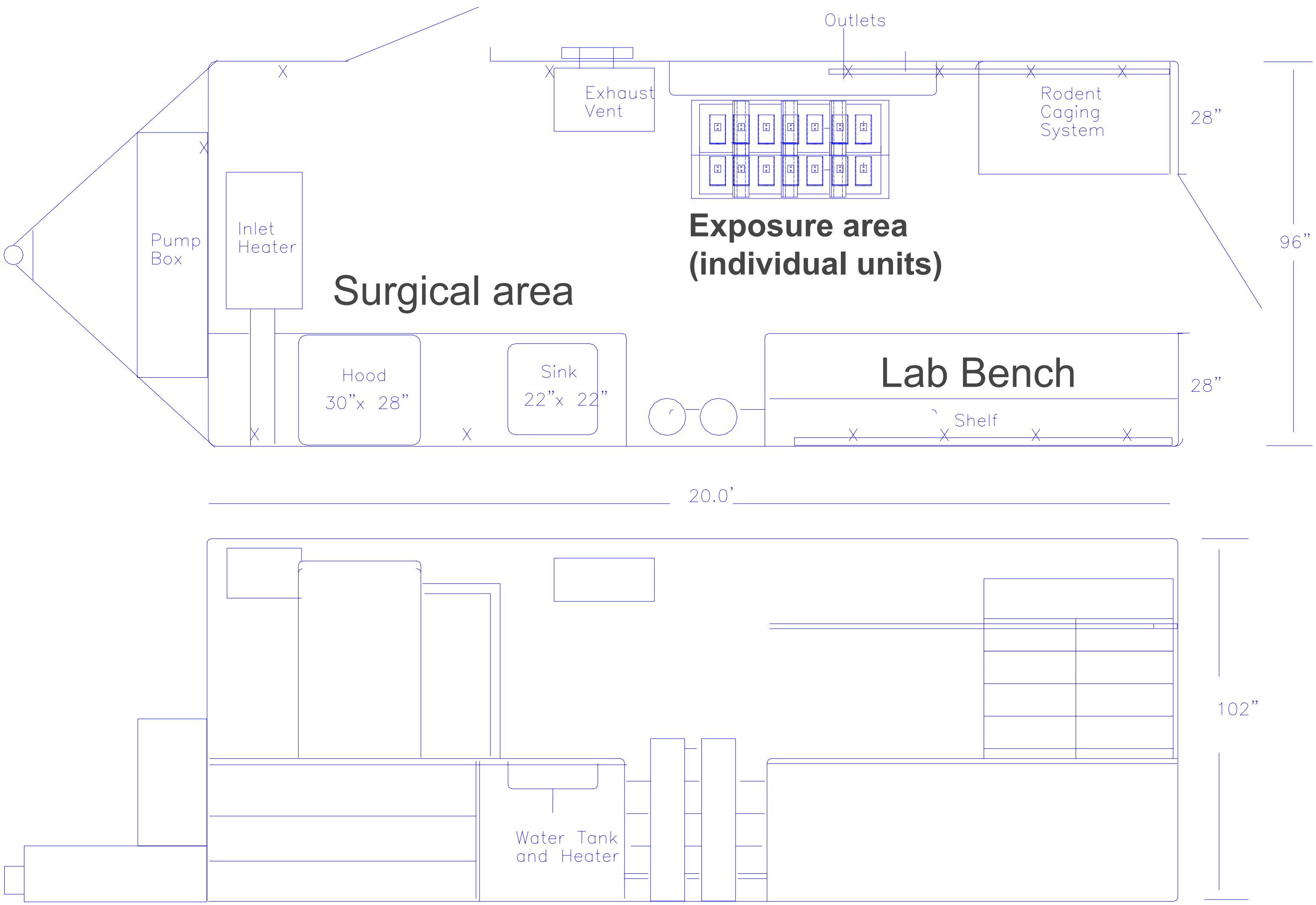
Site	Process for Measurement	Particles	Gases	Other
1	Chamber Input (diluted primary emissions)	Integrated: mass Semicontinuous: elements (Streaker)	---	---
2	Chamber Performance (alternating up and downstream)	Continuous: APS and SMPS (size distribution)	Continuous: SO_2, CO, NOx, O_3	---
3	Chamber Output (aged emissions)	Integrated: Mass, SO_4^{2-}, NH_4^+	Integrated: NH_3, DNPH cartridges for selected carbonyls	Continuous: T, RH
4	Exposure Chamber (diluted aged emissions)	Continuous: TEOM (mass), CPC (total count), aethalometer (BC) Semicontinuous: elements (Streaker) Integrated: mass, SO_4^{2-}, H^+, NO_3^-, NH_4^+, EC/OC, organics	Continuous: SO_2, CO, NOx, O_3 Integrated: NH_3, carbonyls	Continuous: T, RH

Animal Exposures and Toxicological Assessment

- Staged approach using normal and “compromised” rats.
- 4-hour exposures, with 1-hour baseline and recovery periods (room air).

Mobile Toxicological Laboratory

Mobile Toxicological Laboratory Layout



Interior Work Benches, Sink, Hood, Storage

Thoren Cage Unit (without filter system)

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Stage I Assessment

- Normal rats.
- All exposure scenarios.
- Endpoints evaluated:
  - Pulmonary function/breathing pattern
  - *In vivo* oxidative stress via chemiluminescence
  - Blood cytology
    - Total white blood cell counts
    - Differential profiles
  - Bronchoalveolar lavage:
    - Cellular content (cell viability, total cell counts, cell type)
    - Markers of pulmonary injury (lactate dehydrogenase (LDH), β–n-acetyl glucosaminidase (βNAG), total protein)
  - Pulmonary histopathology

Stage II Assessment

- Scenario showing the greatest response in Stage I
- Rat myocardial infarction (MI) model
- Endpoints evaluated:
  - Cardiac function via electrocardiography (implanted telemeters)
    - Heart rate
    - Heart rate variability (SDNN; standard deviation of the normal beat-to-beat intervals)
    - Arrhythmias
  - Blood chemistry (endothelin-1, C-reactive protein, interleukins-1 and 6, TNFα)
  - Pulmonary function/breathing pattern

Mobile Source and CAPs Assessment

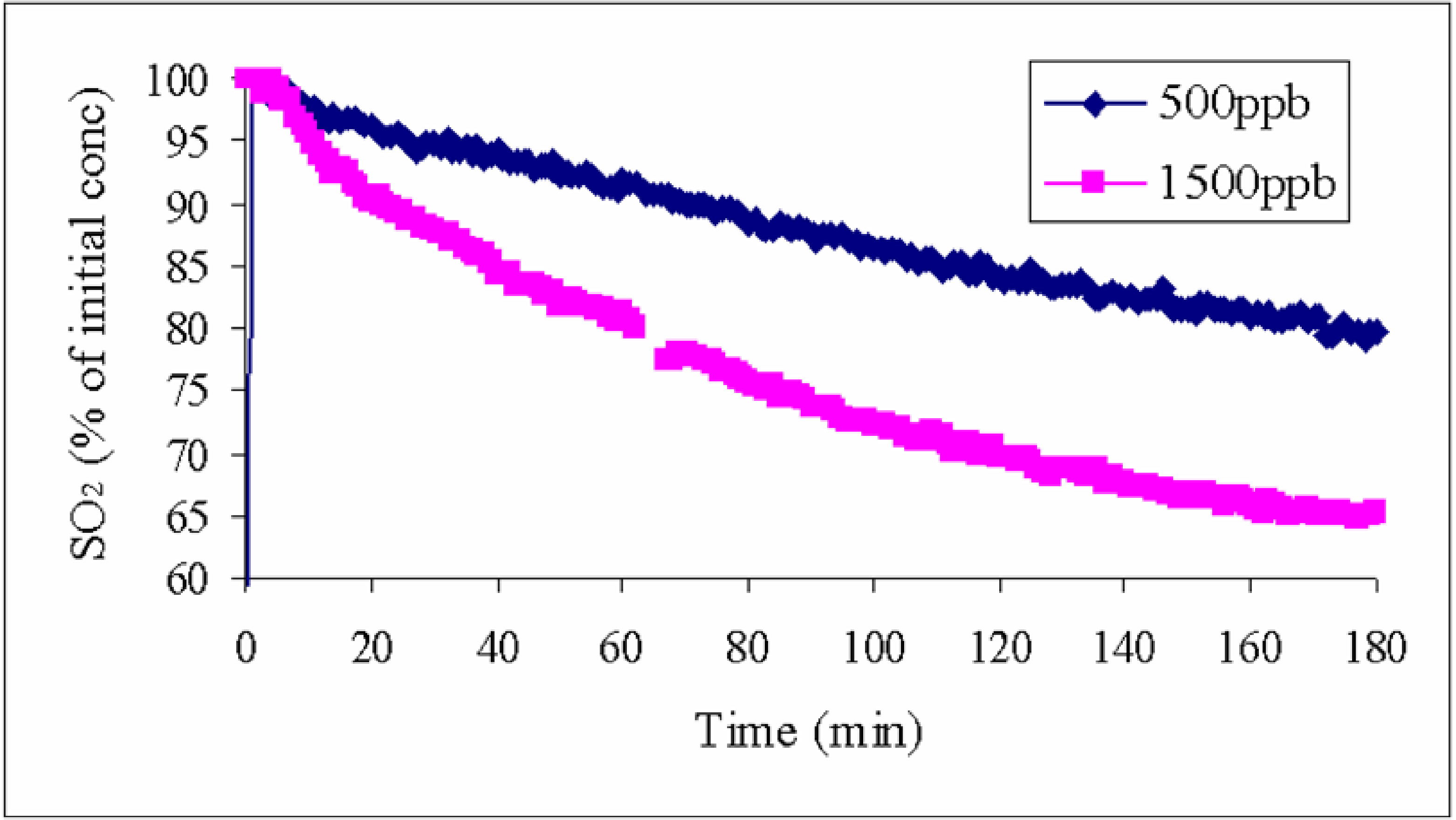
- Mobile source assessment:
  - Sample diesel and/or gasoline engines (specific age and type TBD).
  - Methods for atmospheric simulation, animal exposure, and toxicological assessment will be completely analogous to the methods used for coal combustion emissions.
- Concentrated ambient particles (CAPs):
  - Use existing data from the Harvard School of Public Health laboratory.

Laboratory Results: Reaction Chamber Performance

Reaction Chamber Performance

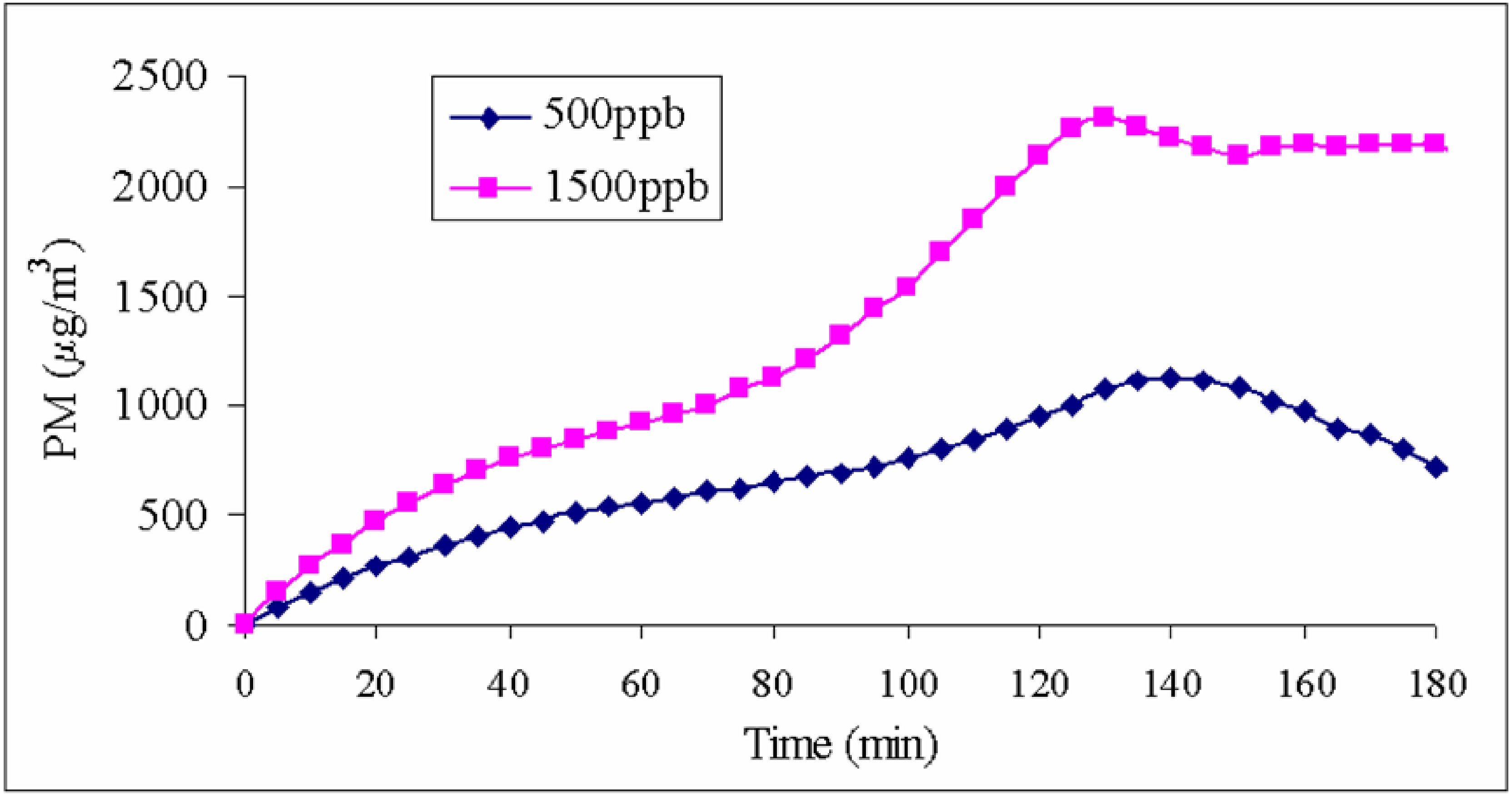
- Simulated emissions were used to test the ability of the reaction chamber to oxidize diluted power plant emissions: emissions consisted of a mixture of SO_2 and NO in the same concentration ratio as expected at the first field power plant in the Upper Midwest (ppbNO/ppbSO_2 = 0.6), and a stack dilution of 1:200.
- Photolysis of ozone was used to produce OH radicals.
- RH = 50%, T = 30 C, residence time = 60 minutes, and chamber flow = 5 LPM.
- Equilibration was first carried out: mixture of gases was equilibrated inside the chamber for enough time to achieve steady concentrations of NO, NO_2, SO_2, and O_3 (no light).
- The reaction was initiated when UVB-313 lamps were turned on.

Conversion of SO_2: Effect of O_3 Concentration



SO_2 conversion rate approximately 25% at 500 ppb O_3 and 40% at 1500 ppb O_3

Aerosol Formation: Effect of O_3 Concentration



Observed and expected mass measurements are roughly in good agreement.

Application of Laboratory Results to Fieldwork

- Laboratory work documents the validity of the reaction chamber in oxidizing simulated emissions to form particles.
- During fieldwork, it is expected that the ozone concentration will be approximately 1000 ppb; however, the gas-permeable membrane (analogous to a nonspecific denuder) will allow removal of excess ozone (and other gases), while maintaining sufficient secondary aerosol for exposure.
- Target PM exposure concentrations are in the order of 200 – 300 $\mu g/m^3$.

Project Scope of Work

Prior to the start of the EPRI-DOE Cooperative Agreement, the following work will have already been completed under the TERESA program with non-DOE sources of funding:

- Construction of the reaction chamber and associated equipment;
- Development and validation of the atmospheric simulation methods;
- Outfitting of the mobile exposure laboratory;
- Construction and installation of the emissions sampling/dilution system at the Upper Midwest plant;
- Aging of the primary emissions from the Upper Midwest plant;
- Exposure of normal and compromised rats to emissions from the Upper Midwest plant subjected to different simulated atmospheric conditions;
- Physicochemical characterization of the various exposure scenario atmospheres at the Upper Midwest plant; and
- Toxicological evaluation of the Upper Midwest scenario atmospheres.

Task 1 – Completion of Field Study at Upper Midwest Plant

- Task 1.1: Laboratory Analysis of Air Quality Data
  - Analysis of filter samples (mass, elements, ions, EC/OC)
  - Processing/validation of continuous data
- Task 1.2: Integration, Analysis, and Interpretation of Air Quality and Health Effects Data
  - Comparison of effects observed during the 6 exposure scenarios
  - Assessment of the effect of PM composition on response

Task 2 – Field Study at Power Plant #1

- Task 2.1: Installation and Operation of Stack Sampling/Dilution System
- Task 2.2: Installation and Operation of Atmospheric Reaction Simulation System
- Task 2.3: Installation and Operation of Animal Exposure Laboratory
- Task 2.4: Performance of Toxicological Assessments
- Task 2.5: Laboratory Analysis of Air Quality Data
- Task 2.6: Integration, Analysis, and Interpretation of Air Quality and Health Effects Data

Task 3 – Field Study at Power Plant #2

- Task 3.1: Installation and Operation of Stack Sampling/Dilution System
- Task 3.2: Installation and Operation of Atmospheric Reaction Simulation System
- Task 3.3: Installation and Operation of Animal Exposure Laboratory
- Task 3.4: Performance of Toxicological Assessments
- Task 3.5: Laboratory Analysis of Air Quality Data
- Task 3.6: Integration, Analysis, and Interpretation of Air Quality and Health Effects Data

Task 4 – Evaluation of Relative Toxicity of Coal Plant Emissions, Mobile Source Emissions, and CAPs

- This task is not funded by DOE, but is being conducted by HSPH with support from the Harvard/EPA Center for Ambient Particle Health Effects.
- Sampling of diesel and/or gasoline engines.
- Type, age, etc. will be decided through a consultative process with individuals of appropriate expertise.
- CAPs assessment will be done using existing data from the HSPH laboratory.

Task 5 – Preparation of Peer-Reviewed Journal Articles

- Critical component of the DOE-EPRI Cooperative Agreement.
- At least 3 peer-reviewed articles will be prepared and submitted on the following three topics:
  - Results of the atmospheric simulation and generation of exposure atmospheres.
  - Results of the coal combustion emissions toxicity assessment.
  - Comparative toxicity assessment for coal combustion emissions, mobile source emissions, and CAPs.

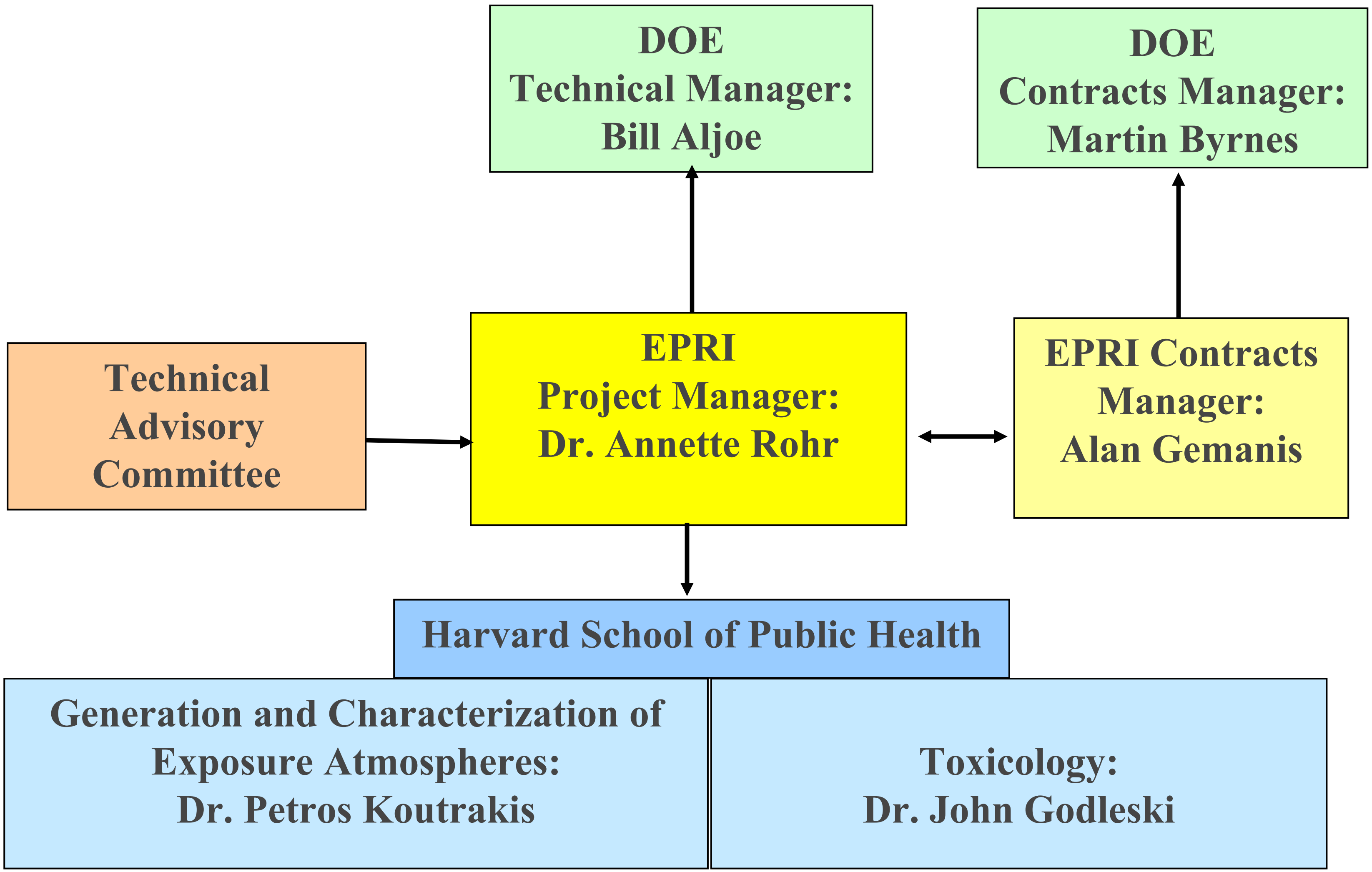
Task 6 – Project Management and Reporting

- All planning, management, and coordination activities associated with the project.
- EPRI will:
  - Coordinate all field, laboratory, data management, and data analysis activities of the subcontractor (HSPH);
  - Arrange appropriate power plant site access;
  - Be responsible for all deliverables and briefings.

Project Administration

- Project Team
- Project Schedule
- Project Deliverables

Project Team

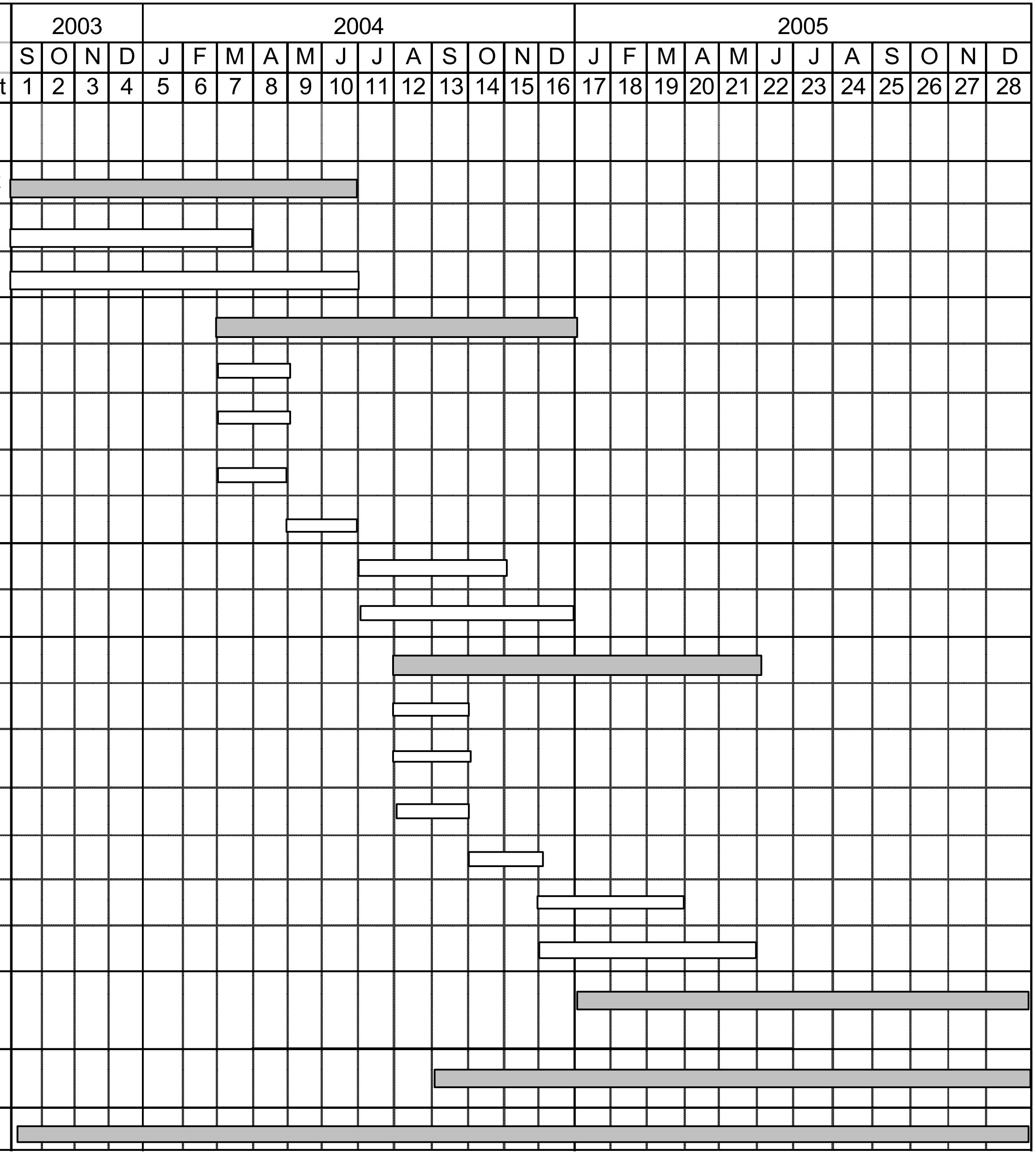


Technical Advisory Committee

- Comprised of:
  - Dr. Joe Mauderly, Lovelace Respiratory Research Institute (Toxicology)
  - Dr. Bruce Miller, The Pennsylvania State University (Combustion Engineering)
  - Dr. Ken Sexton, University of North Carolina (Atmospheric Chemistry)
- TAC meetings were convened on February 11 and September 25, 2003. The next TAC meeting will be conducted during the course of the fieldwork at the Upper Midwest plant.
- The TAC will convene yearly at a minimum.

Project Performance Schedule

Task	Subtask	Description
1		Complete Study at Upper Midwest Plant
	1.1	Laboratory Analysis of Air Quality Data
	1.2	Data Integration and Analysis
2		Field Study at Power Plant #1
	2.1	Stack Sampling/Dilution System
	2.2	Atmospheric Reaction Simulation System
	2.3	Animal Exposure Laboratory
	2.4	Toxicological Assessments
	2.5	Laboratory Analysis of Air Quality Data
	2.6	Data Integration and Analysis
3		Field Study at Power Plant #2
	3.1	Stack Sampling/Dilution System
	3.2	Atmospheric Reaction Simulation System
	3.3	Animal Exposure Laboratory
	3.4	Toxicological Assessments
	3.5	Laboratory Analysis of Air Quality Data
	3.6	Data Integration and Analysis
4		Relative Toxicity of Coal Plant and Mobile Source Emissions and CAPs
5		Preparation of Peer-Reviewed Journal Articles
6		Project Management and Reporting



Project Deliverables

- Four semi-annual reports.
- Comprehensive final report at project conclusion.
- Topical reports on the results of the animal exposure experiments at each of the three power plants.
- Minimum of 3 manuscripts for peer-reviewed journals.